Human Factors Engineering: An Enabler for Military Transformation

Through Effective Integration of Technology and Personnel

Proposed Track

C2 Assessment and Cognitive Analysis

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Abstract

Transformation of the United States military requires new ways of defining both design and mission processes to improve warfighting performance and reduce system costs. New technologies engendered through the discipline of human-factors engineering enable warfighters to make more effective decisions in a timelier manner with fewer personnel. While the tradeoffs between new technologies and numbers of operators needed are complex, strong anecdotal evidence suggests that these manpower savings can be significant and have the potential to accelerate military transformation. The human factors engineering community has documented and quantified the enhanced mission effectiveness of fewer warfighters operating enhanced combat systems. What is less well quantified – due to a number of institutional factors - is the true life cycle cost of military operators. This paper discusses design factors that support reduced crew workload and factors that influence crew cost estimation and size. The conclusion is that although we have identified good candidate designs to support reduced crew workload, we cannot adequately trade off their cost with personnel costs until we can more accurately quantify personnel costs.

Human Factors Engineering: An Enabler for Military Transformation

Through Effective Integration of Technology and Personnel

The major institutions of American National Security were designed in a different era to meet different requirements. All of them must be transformed.

President George W. Bush
National Security Strategy of the United States
September 20, 2002[1]

When asked what single event was most helpful in developing the theory of relativity, Albert Einstein is reported to have answered, "Figuring out how to think about the problem."

Men, Women, Messages and Media:
Understanding Human Communication[2]

Introduction

As the United States' military transforms, warfighters are increasingly turning to technologists to solve vexing operational challenges through the effective application of emerging technologies. One of the most critical intersections of operational needs and technological solutions is in the multi-dimensional concept of command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR). Within the overarching discipline of C4ISR, effective use of human-systems technologies enables warfighters to make faster and better decisions. These technologies present some of the most exciting possibilities for enhancing the warfighting effectiveness and efficiency of a U.S.-led joint or coalition force. These human-systems technologies may assist the operator and warfighter in a number of ways: 1. enabling more effective decisions to be made; 2. enabling decisions to be made in a more timely manner; and 3. reducing the number of personnel needed to operate platform, sensor and weapons systems.

The value of these technologies in the area of enabling more effective and more timely decision-making has been observed and quantified in recent Space and Naval Warfare Systems Center-San Diego (SSC-SD) projects such as the Multi-Modal Watchstation (MMWS) and Knowledge Wall/Knowledge Web. The software associated with decision-aiding and improved visualization reduces workload by augmenting or replacing manually-intensive tasks with automated support. The relationship between this technology and crew size and cost is often obscured by the lack of one-to-one correspondence between a software technology unit cost and a resulting shipboard position change. Typically, the newer hardware technology is both more capable and cheaper than the old. Software development and testing becomes the chief cost driver.

Tradeoffs between the costs of these systems and the cost savings achieved by requiring fewer personnel to operate these systems could be a significant factor in determining if or how quickly these technologies transition to acquisition. For this reason, it is important to understand the manpower savings effected by various human-systems technologies as well as the concomitant manpower costs associated with continuing to utilize additional operators to employ legacy systems. This understanding – figuring how to think about the problem - is crucial if we are to transform the United States military and effectively use technology to enable manpower savings aboard Navy and Joint ships, aircraft and command centers.

Transformation – Man and Machine

Transforming the United States Military

Transformation of the United States military has been a strong theme of President George W. Bush since well before his administration began its term in January 2001. Candidate Bush signaled the course for military transformation in a speech at the Citadel in September 1999 where he stated: "I know that transforming our military is a massive undertaking…The real goal is to move beyond marginal improvements – to replace existing programs with new technologies and strategies. To use this window of opportunity to skip a generation of weapons systems."[3]

This theme of military transformation has remained consistent – and has been reinforced - in the years that the George W. Bush Administration has been in office. This has been articulated in several *Transformation Studies* commissioned by the Secretary of Defense; in the *Quadrennial Defense Review Report*; in the *Secretary of Defense 2002 Annual Report to the President and the Congress*; as well as in the *National Security Strategy*.[4] The *Secretary of Defense 2002 Annual Report to the President and the Congress* put a punctuation mark on the importance of military transformation by noting that: "We owe it to our posterity to begin a sustained process of investment and military transformation to meet and dissuade future challenges. Transformation lies at the heart of our efforts to reduce risk posed by future challenges."

Transforming the United States Navy

The Department of the Navy has invested substantial intellectual capital in coming to grips with how to transform the Navy and the Marine Corps in order to make them more effective contributors to a transformed United States military. Innovative concepts dealing with Navy and Marine Corps transformation have been generated in venues such as the Chief of Naval Operations Strategic Studies Group, the Navy Warfare Development Command, the Marine Corps Warfighting Laboratory, the Chief of Naval Operations Executive Panel and the Naval Operations Group (Deep Blue).

The Department of the Navy's plans for transformation were formally articulated in *The Naval Transformation Roadmap*, released in July 2002. Co-signed by the Secretary of the Navy, the Chief of Naval Operations, and the Commandant of the Marine Corps, this document set a clear course for transforming the Navy and the Marine Corps.[5] The vision presented in this roadmap was first publicly announced by the CNO at the June 2002 Current Strategy Forum at the Naval War College in what he called *Sea Power 21: Operational Concepts for a New Era.*[6] This new Sea Power 21 operational concept was later refined in a series of articles in the *U.S. Naval Institute Proceedings*, beginning in October 2002 and continuing for four additional issues.[7] This series of articles represented a clear call for profound transformation of the Navy.

Transformation is not just about technology. An important part of this military transformation involves changes in policies, procedures and designs that improve performance and save costs. Key tenets of *Sea Power 21* are designed to focus the efforts of designing systems that enable warfighters to make better and more timely decisions with fewer personnel.

The Navy has embarked upon a determined effort to do just this. In the Navy's *Fiscal Year 2003 N1 Playbook*, the Chief of Naval Personnel, Vice Admiral Norbert Ryan, notes: "The design of new systems must include Sailors from the start."[8] In one effort to ensure that the imperative of substituting technology for manpower is given appropriate focus, the Naval Sea Systems Command has created a directorate within (Sea 03) specifically charged with human-systems integration.[9]

Anecdotal evidence suggests that the Navy is committed to efforts to reduce the number of sailors on ships. For example, in the case of the Navy's CVN-21 program, the Navy did not originally plan to build a carrier capable of being manned by 800 fewer people until the second ship of the new class. The initial plan called for CVNX-1, starting in 2007 for commissioning in 2014, to reduce the crew by about 400 and for the later CVNX-2 to reduce it by 400 more. However, those requirements changed dramatically in the fall of 2002, requiring the first ship of the new CVN-21 class to have 800 fewer sailors than the current Nimitz Class carriers.[10]

Efforts to utilize technology to reduce manning are not limited to new-construction ships. For example, the Naval Sea Systems Command has commissioned an exhaustive study to determine ways that technology can lead to reduced manpower requirements on the Arleigh Burke class destroyers. This study put a punctuation mark on the need to reduce manning on *all* Navy ships by noting that since 1985 the Navy's Total Operating Budget has declined by approximately 40% and ship count by 45%; however, the Operations and Support (O&S) costs (consisting of personnel, maintenance, consumables and sustaining support) have remained constant during this time. This is because personnel costs comprise over 50% of O&S costs and these personnel costs have been growing more rapidly than other costs.[11]

Thus, for both new construction and existing ships, platforms and command centers, there is an ongoing search in the Navy for improved human-systems design and technologies that enhance human performance. These initiatives have been formalized in three key enablers for naval transformation.

Sea Trial, Sea Warrior, and Sea Enterprise: Enabling Naval Transformation

Three supporting processes facilitate the *Sea Power 21* warfighting imperatives embodied in *Sea Strike, Sea Shield* and *Sea Basing*. *Sea Trial*: *The Process of Innovation,* supports rapid concept and technology development and delivers enhanced technology capabilities to our sailors as quickly as possible. *Sea Warrior*: *Investing in Sailors* moves to develop new combat capabilities and platforms that feature dramatic advancements in technology and optimization of crew size. *Sea Enterprise: Resourcing Tomorrow's Fleet* will replace Cold War-era systems with significantly more capable sensors, networks, weapons, and platforms. Significantly, *Sea Enterprise* will substitute technology for manpower to achieve warfighting effectiveness in the most cost-effective manner.[12]

Achieving the vision of *Sea Trial, Sea Warrior* and *Sea Enterprise* presupposes that candidate technologies are now under development that will enable technology to enhance operator performance or substitute for manpower. The complex missions undertaken by naval forces rarely enable manual processes to be replaced by automated ones with a "simple" substitution of technology for operators. Instead the process becomes "mixed," with human supervision of automated processes and human selection of automation levels. With the advent of "smarter" systems that work cooperatively with human supervision, the role of many warfighters shifts from manual control and data input towards strategic thinking and planning. This shift in design focus may allow one operator to supervise processes and systems that were previously controlled by two, three or more operators.

Another key design issue is the quality of human factors engineering regarding process visualization and feedback – particularly important during times of system degradation or unexpected mission events. Thus, automation must be planned carefully and designers must not necessarily take the human out of the information loop just because the control loop is removed in a mission process. In fact, higher quality information may be needed for user understanding of what the automation is doing and what is required during mixed control events.

Thus, cost comparisons of human vs. machine must account for mission processes that contain mixed-initiative systems – where the task initiative is sometimes human and other times automation - and the mission conditions that may cause those automation conditions to change. This involves an assessment of risk and reliability of the mission process, and the potential for human intervention based on political, social, reliability and safety factors. SSC-SD has studied interaction with mixed-initiative systems and developed guidelines to support effective human-system interface design. A discussion of the design techniques used to support various levels of automation is important to understanding the relationship of complex system design and crew optimization.

Human-Factors Engineering – Enhancing Operator Performance

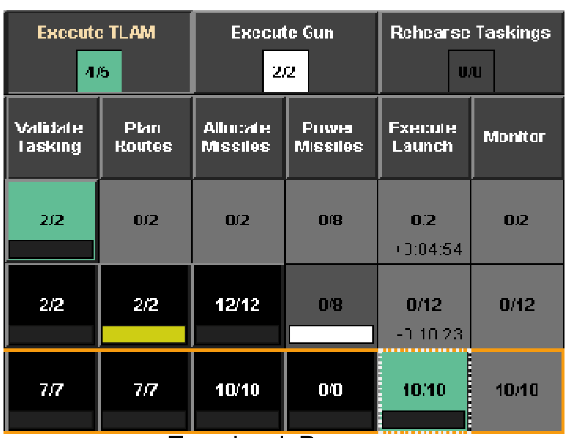
The Office of Naval Research has sponsored ongoing research in Human Factors Engineering concepts at SSC-SD for several decades. Much of the collective knowledge of research in the 1980's and 1990's was summarized in the recent Multi-Modal Watchstation project, and further progressed into two Future Naval Capability (FNC) projects supporting improved Land-Attack systems in Knowledge Superiority and Assurance and Capable Manpower.[13] Lessons learned from the MMWS, Knowledge Wall, and ongoing related research include key issues with regard to successful human-integration with information and control systems performance. These can be summarized into three major factors: 1) human-computer interface (HCI) design, 2) information and software architecture supporting effective human-computer interaction, and 3) effective human factors design process.[14]

These design factors collectively support transformation of mission performance and training simplification. All are accomplished by structured human factors engineering (HFE), a multi-disciplinary field that was formalized in the years following World War II, yet one that is not firmly established in the Navy system engineering process. Effective HFE is driven by: analysis of the work domain; early definition of human support requirements; and design features that best support them.[15] Requirements are defined which reduce human workload and training needs, while enhancing performance results across a wider range of the user population.

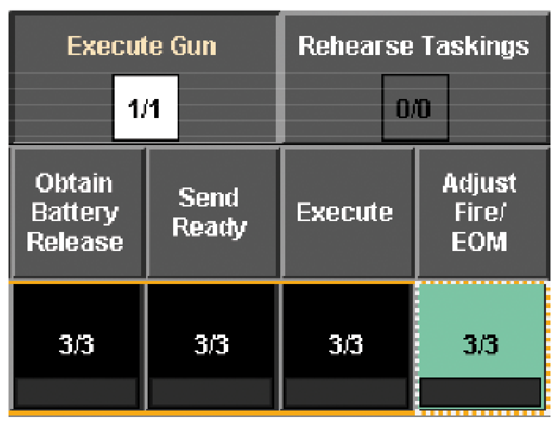
There is a direct, but complex, causal link between effective HFE and personnel costs. Systems that are efficient and easier to operate and maintain likely require fewer personnel resources in all phases of training and operation. Workload imposed by poor design may create both increased personnel burden and reduced mission effectiveness by increasing the risk of mission failure, or by inducing error and delays during peak mission task loads. Design factors with negative impact on human performance or training must be reduced or eliminated to enable effective naval force transformation.

So what is "effective design", and how do we know when we get there? First, work domain and task analysis is a core part of the HFE methodology.[16] SSC-SD has paired the results of the task analysis with the goals of improved HCI design and information support to improve human-system performance. Effective design does not by nature have to be complex or expensive. Sometimes simple solutions produce significant performance gains. For example, in 1991 Office of Naval Research initiatives led to a new method for selecting objects on a display, by changing the way the screen cursor related to the objects and shifting more of the selection work from the human visual and motor systems to the computer.[17] The result improved performance for all types of input devices.

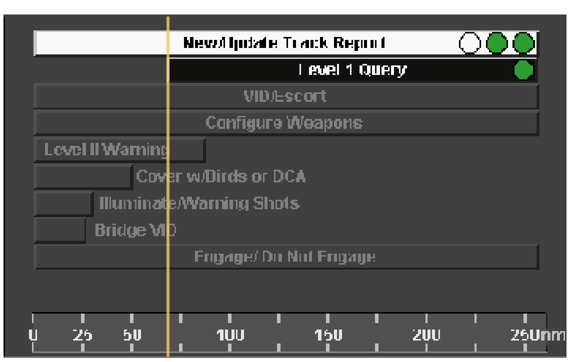
On a much larger scale, human performance is transformed through redesign of the tactical HCI and user interactive process.[18] Results indicated significant improvements in situational awareness and task response for typical Air Defense Warfare team tasks. In both design cases listed above, it was most useful to start from a "blank sheet" of paper and define critical HFE requirements. These requirements and design attributes evolved through research and testing, and are related to a school of thought in HCI design termed as "Ecological Interface" design.[19] This type of design directly reflects and supports the mission process and visualization of that process. As illustrated in Figure 1, dynamic process visualization can be an important feature in supporting mission situation awareness. Tomahawk and Guns reflect step-wise processes while Air Defense is range-based and Engine Propulsion is time-based. Visualization supports important cognitive requirements related to user task roles, responsibilities, past, current, and future status.



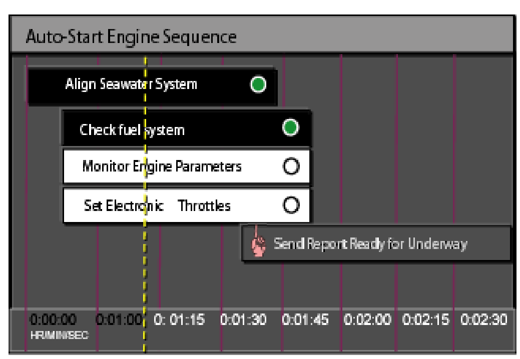
Tomahawk Process



Guns Process



Air Defense Process



Ship Engine Process

Figure 1 Examples of Process Visualization for Various Mission Task Domains

In addition we have identified a key requirement that software functions must support the construction of "work products" – the quality of these products are key performance enablers. These requirements have been summarized recently in the concept of a Goal-explicit Work Interface System (G-WIS).[20] The G-WIS is a representative example of "Work Centered Computing."[21] The G-WIS visualization does not presume an "office" Graphic User Interface (GUI) look or feel. HCI tools within that metaphor have been found sometimes to be impediments to the efficient performance required in fast-reaction weapons systems.[22] The significant performance enabler is not the HCI look and feel, but instead the quality and robustness of the task products and their contribution to the mission process. Results in current work for Tomahawk and land attack systems have been promising, as the performance enabling properties of the G-WIS design approach have become apparent from fleet performance and usability testing.[23]

To ensure success, the product must be of sufficient quality to transform the role of the warfighter from skill and rule-based procedures toward knowledge-based work activities. In this manner, the warfighter becomes an informed supervisor of mission processes and can devote cognitive resources to critiquing products and planning ahead – enabling pro-active decision making with greater speed and accuracy. The degree of impact on manning and transformation is directly related to the product quality and availability across the gamut of planning, execution, monitoring, and re-planning mission domains in tactical, operational, and strategic systems. Determining the cost of effective task products for key mission processes is critical for tradeoff analysis of technology versus manual labor.

The mission process and product requirements are captured through structured analysis of workflows and captured in HFE sequence diagrams and software Use Case and Activity Diagrams. Figure 2 presents a typical workflow analysis showing the actions of human, system, and external entities by showing the path of information flow and processes. Links to display examples are shown in the diagram for viewing the content of decision aids at that point in the process flow. The workflows are also part of the Design Reference Missions, which contain the workload and mission demands required of the human-system combination. A significant benefit from the workflow analysis is the revelation of process flaws and gaps that can be improved. This may include a reduction of steps or methods that may be unnecessary artifacts from legacy systems or part of an inefficient product approval chain. Understanding a mission process and improving it is critical to support crew optimization and naval transformation.

The link between performance improvement, efficiency, and crew size is still ill defined, even given the performance benefits from the human engineering process and qualities of the prototype systems mentioned above. Also, several of the job positions in the Air Defense teamwork example noted above were related to monitoring communication circuits with requirements driven by coalition forces or battle group requirements. For example, if three voice circuits must be manned to monitor traffic and make reports, the entire force communication protocols and methods must be changed to enable crew optimization. This, of course, is possible, given digital communications and text messaging technology, but it also points out the multiple system factors that impact crew workload across a mission protocol, group operations, and equipment constraints between coalition forces.

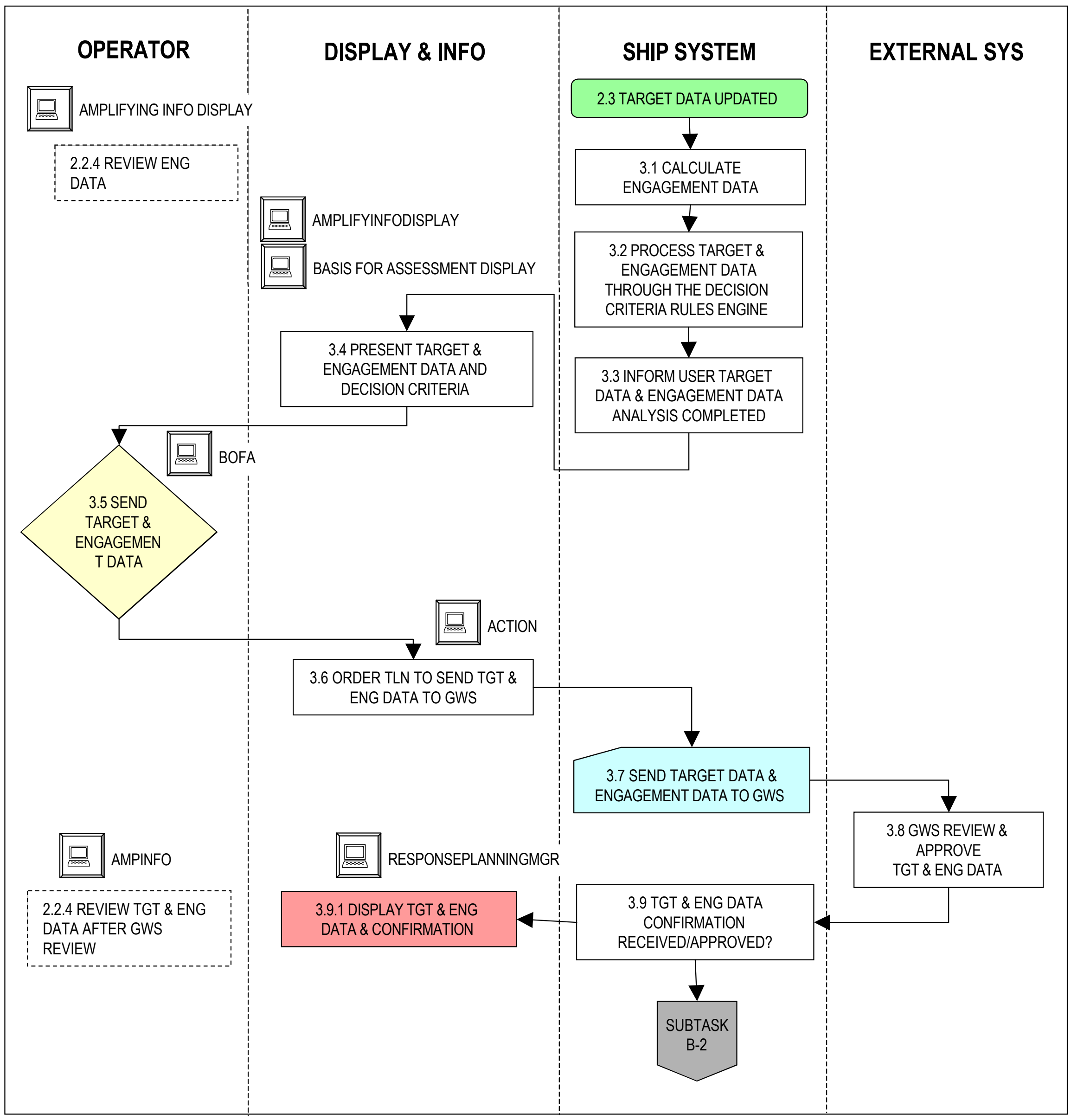


Figure 2 Process Work-flow Analysis Showing Human, System and External Information Flow

Thus, the complexity of measuring the impact of Human-System Integration cuts across technology, system integration and mission processes and protocols. As defined above, automation is not a dichotomy existing in either an “off” or “on” state, but instead a continuum across multiple levels of human supervisory control. Models cannot simply trade off automation for human processing one-to-one. Given the interaction between design and process factors, each factor must be included in models that estimate design impact on crew workload and crew size. Towards this end, the models that define cost variables impacting crew size and cost must be as accurate and objective as possible.

Manpower Cost Analysis – Still an Imperfect Science

Regardless of how effective various human-systems technologies are in enhancing operator performance and enabling the substitution of technology for manpower, ultimately, cost weighs heavily on strategic decisions regarding which human-systems technologies to buy and install on platforms, systems and command centers. Decisions will be made within the context of tradeoffs between the cost of such new systems and the concomitant manpower savings affected if these new systems are installed.

These important tradeoffs should be made in an objective manner with reliable metrics to guide the Services toward the correct decisions. This paper has noted that in the case of many technologies, the extent to which these new technologies enable more effective human performance has been quantified, with strong potential for reducing crew size. The extent of cost savings from crew reduction is not readily evident due to the granularity of metrics to determine the “real” cost of an officer or an enlisted person.

Strong anecdotal evidence suggests that the metrics used to quantify the cost of an officer or an enlisted person provide only rough approximations of these costs. While there are many reasons for this, an exhaustive study by the Center for Naval Analysis concluded that, within the United States Navy, there are insufficient organizational imperatives to mate technology and manpower decisions.[24] This CNA study compares the methods that the Navy uses to quantify “true” manpower costs with methods used by the private sector and concludes that the Navy could learn a great deal from the private sector in the way in which the Navy assesses the allocation of resources based on costs, technology, and available labor.

For example, the Workyear Rates promulgated by the Chief of Naval Operations to determine Future Year Defense Plan (FYDP) requirements for manpower provide a single rate for officers and a single rate for enlisted personnel, making no distinction among paygrades.[25] This averaging of rates across pay grades skews any attempt to derive objective data regarding personnel costs. This may tend to make legacy systems appear to be as cost-effective as new human-systems technologies by obscuring the fact that more junior, less-experienced personnel can be trained on new systems that supplant legacy systems that required more experienced operators.

While Navy manpower models purport to include all costs of manpower (and they do a reasonable job of that) what they do is quantify that which is readily quantifiable while omitting some important costs that do impact the "life cycle cost" of an officer or a enlisted person. For example, the Navy "model" does not readily factor in recruiting costs or all training pipeline costs, often obscuring the extremely long pipeline training for some personnel such as aviators and nuclear trained officers. The model is also not easily adapted to factor in extraordinary costs of a war when tens of thousands of Navy personnel receive special pay for being in a war zone. Additionally, there is no way to factor in the vast infrastructure of Family Support Centers, Child Development Centers, and similar entities that are part and parcel of supporting families of sailors.

Beyond the life cycle costs of officers and sailors that are borne by the Department of Defense are costs borne by the Nation for each person who serves in uniform. As life-expectancies grow, the Veterans Administration benefits that are paid to post-service and post-retirement military personnel *for life* represent a growing tax burden that must be made up from other accounts. Additionally, the extraordinary costs of a war when hundreds of thousands of military personnel are rushed into a hostile area during operations such as Operation Iraqi Freedom include well-deserved tax breaks for military personnel that nonetheless result in a significant decrease in tax revenue.

In short, while manpower analysts have done a credible job of deriving a first-order approximation of Navy manpower cost, institutional factors auger against their refining these metrics to make it a sharp instrument to enable objective manpower-technology tradeoffs to be made. Unless or until these models are refined, manpower cost analysis will remain an imperfect science.

Conclusions and the Imperatives Further Research

Military transformation will continue to demand that technology replace manpower on platforms, systems, and command centers. HCI technology can enable mission processes to be completed in a timely and effective manner with fewer personnel. Quite often, the roles of warfighters will need to shift toward supervisory control of multiple mission processes vs. manual control of a single mission process. Software systems must be designed to produce high-quality mission products enabling warfighters to do more with fewer personnel. In many cases, costs for duplicate functionality can be shared across systems thereby reducing the cost of automation or decision support. The costs of better automation and high quality software mission products must be compared to the "true" cost of personnel.

Directly comparing the manpower costs to systems development and maintenance costs does not always tell the entire story, nor does it necessarily provide a complete and objective analysis. The quality and reliability of performance, coupled with the speed, accuracy and efficiency of decision making ultimately impact the mission performance of these operators. Clearly, this is an area requiring more research and modeling to determine the viability of coordinating the optimal mix of smarter systems and crew size.

It also demands research that will lead to more effectively defining the “true cost” of an officer or an enlisted person on Navy ships.

This is an area that demands the immediate attention of the Office of the Secretary of Defense and the Department of the Navy. Failure to do the important research involved in measuring these tradeoffs could ultimately retard efforts that integrate smarter systems and processes and contribute to reduced crew size on Navy platforms. If this analysis is not conducted it will increase the risk that these “manpower-heavy” Navy platforms will become unaffordable, inhibiting Department of the Navy transformational initiatives and reducing the contribution that the Navy can make to the National Security of the United States.

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4. See, for example, James McCarthy, et al, *Transformational Study Report: Transforming Military Operational Capabilities* (Washington, D.C., Department of Defense, April 27, 2001), *The Quadrennial Defense Review Report* (Washington, D.C., Department of Defense, September 30, 2001), and *Secretary of Defense Annual Report to the President and the Congress* (Washington, D.C., Department of Defense, August 2002). The theme of military transformation has remained consistent throughout these extensive reports.

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Human Factors Engineering–An Enabler for Military Transformation Through Effective Integration of Technology and Personnel

George Galdorisi & John R. Kammerer
SSC San Diego

Eighth International ICCRTS Conference

June 17-19, 2003

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The major institutions of national security were designed in a different era to meet different requirements. All of them must be transformed

President George W. Bush

National Security Strategy

September 20, 2002

Outline

- Military Transformation – Key Enabler
- Transformation Limits - Budget Pressure
- C4ISR Transformation – Critical Nexus
- Human Factors Engineering – Results
- Transformational Tradeoffs
- The C4ISR Transformation Challenge

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When asked what single event was most helpful in developing the theory of relativity, Albert Einstein is reported to have answered, “Figuring out how to think about the problem”

Men, Women, Messages and Media: Understanding Human Communication

Military Transformation Enabler for Warfighting Effectiveness

- Transformation pressures
  - New systems compete with legacy systems
  - Desire to field systems with fewer people
- Building systems around the warfighter
  - Testing the limits of human performance
  - Building cost-effective systems and platforms
- Fighting the next war – not the last one
- Accelerating new technology insertion

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I know that transforming our military is a massive undertaking…The real goal is moving beyond marginal improvements – to replace existing programs with new technologies and strategies. To use this window of opportunity to skip a generation of weapons systems

President George W. Bush

Citadel Speech

September 23, 1999

Transformation Pressures

- Transformational systems often compete with existing legacy systems
- “Burden of proof” often falls to these systems to prove their value-added
- Metrics to measure transformational systems often not well-developed
- Built-in inertia of existing systems and desire to make incremental changes

Building Systems Around The Warfighter

- New systems will need to be developed around the warfighter
- Changes already underway at several levels (example: NAVSEA 03)
- Methodology implies that objective, metric-based analysis will be done
- Nexus of budgets, technology, and personnel costs

Limits to Military Transformation: Budget Pressures for all Nations

- New technologies often offer great promise
- Transition to new systems requires tradeoffs
- Budget pressures often suggest either/or paths must be taken
- Metrics to determine “what a pound of C4ISR is worth” are not robust

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In today's world it is *inconceivable* that anything could be accomplished outside of a coalition operation

Dr. David Alberts

Seventh International ICCRTS

September 16, 2002

New Technology vs. More People Important Tradeoffs

- Costs of new systems and platforms
- Costs of manning legacy systems
- Manpower part of systems costs
- Systems designed “around the human”

Costs of New Systems and Platforms

- New technologies appear to offer substantial manpower savings benefits
- Discipline of Human Factors Engineering now part of the design process
- Process *assumes* objective and quantifiable tradeoffs are made
- Acquisition community seeking metrics to balance new systems costs

Costs of Manning Legacy Systems

- USN Study – last two decades:
  - USN TOB has declined by 40%
  - USN ship count has declined by 45%
- USN Operations and Support Costs (O&S)
  - O&S Costs have remained constant
  - Personnel costs comprise over 50% of O&S

C4ISR: Critical Nexus for Military Transformation

- C4ISR systems – leading edge technology
- Navy & DoD impetus to transform rapidly
- Technology substitutions often complex
- Role of warfighters may need to change

C4ISR Systems Create Opportunities for Military Transformation

- C4ISR systems offer high-payoffs to replace manpower with technology
- U.S. Navy has established this as an important goal of Sea Power 21
- Complex naval missions rarely enable “simple” substitution of technology for operators
- Key appears to be shifting the role of warfighters from manual control and data input to strategic thinking and planning

Cost Comparisons: Man vs. Machine

- Must account for mission processes that contain mixed-initiative systems
- In these systems, the task is sometimes human and other times automated
- Examining interactions within mixed-initiative systems supports effective HCI
- Design techniques have been tested to enable various levels of automation

Human Factors Engineering: Leading C4ISR Transformation

- Making better decisions
- Making decisions faster
- Using fewer personnel

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Office of Naval Research Sponsored Research

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- Research spans two decades under the auspices of Future Naval Capabilities
  - Knowledge Superiority and Assurance
  - Capable Manpower
- Research products focused on:
  - Human-computer interface (HCI) design
  - Architectures for human-computer interaction
  - Effective human factors design process

Lessons Learned and HFE Results

- Direct and causal link between effective HFE and personnel costs
- Increased workload imposed by poor design = reduced mission effectiveness
- This manifests itself by inducing error and delays during peak mission task loads
- Pairing of task analysis with improved HCI design dramatically improves results

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Human-Computer Interaction Key Areas

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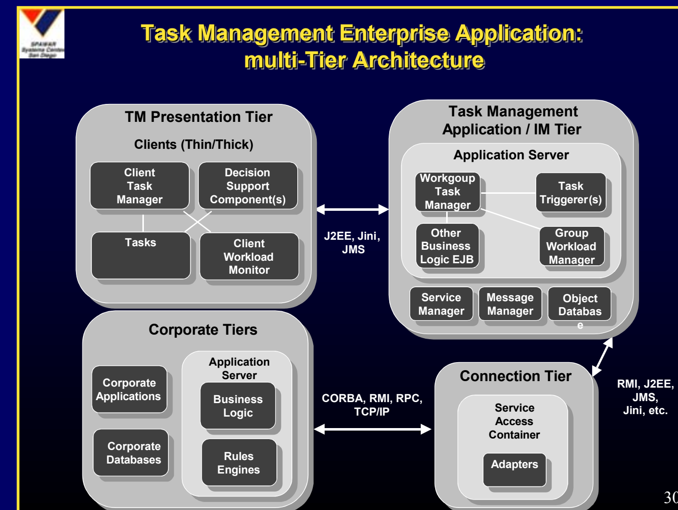
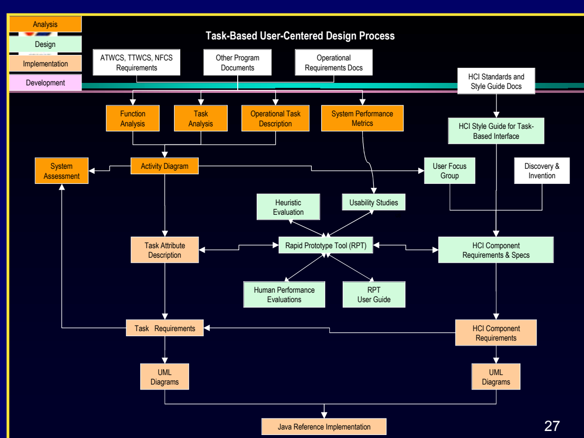
- Common & Reusable Process Supervision Aids
- Common Procedures and simple training



Reusable Task Management & Information Architecture across C4I Levels



Task-Centered Design Process

- Team/Individual Workspace
- Productive & Efficient Teams
- Team/Individual Performance Metrics

Crew Optimization

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- Supervisory Control Design Requirements.
  - Human performance gains - speed/accuracy/reliability
  - Mission process gains.
  - Training simplification.
- Use design lessons learned from R&D.
- Use iterative design process with frequent testing.
- Challenges:
  - Raising design expectations and reducing risk.
  - Existing design process & procurement.
  - Design issues with cooperative automation.
  - Design issues with distributed team workload & perform.

Software Produces Quality Work Products

- TTWCS water & land routes
- Missile cell allocation plan
- Flex-target missile re-allocation plan

Other Examples:

- Strike Mission Plan
- Air Defense Battlegroup Track Reports
- Target Weaponeering plan
- Ship transit & logistics plan
- Communications plan
- Force positioning plan
- Electrical/propulsion underway sequence

Products are harder to draft when multiple systems hold the information required!!

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G-WIS HCI Model

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C2 Information Hierarchy

Operations View -
Across Missions

Mission View -
Across Systems

Mission View -
Specific Goals/Work Tasks

Planning	Execution
Monitoring	Re-planning

Work Task Details

Work Products

Alternatives & Explanations

Mission and Situation Visualization

Cognitive Requirements

What do I do next?

What are variables?

Pros & Cons?

What if?

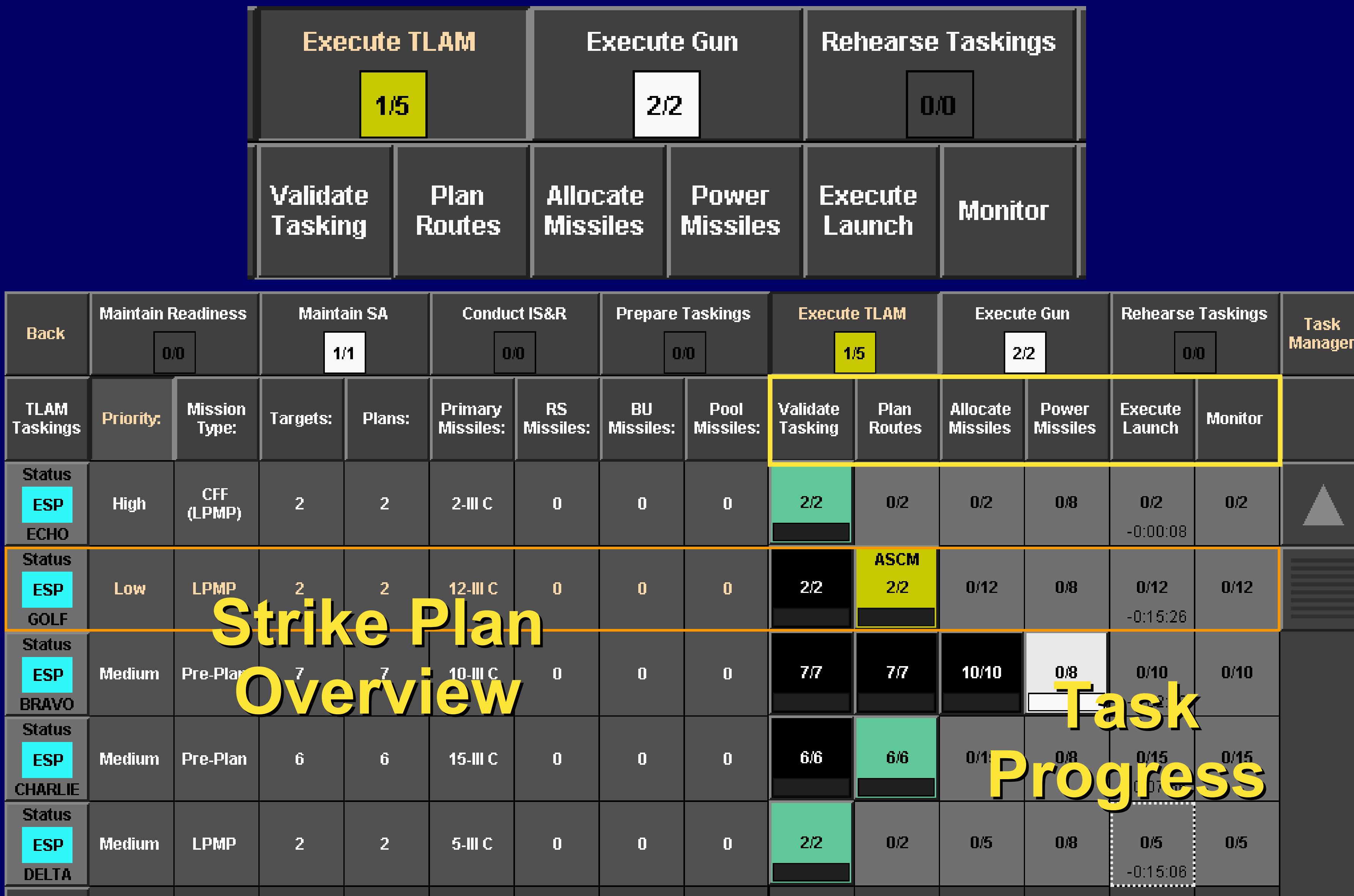
Next step(s)

What's optional?

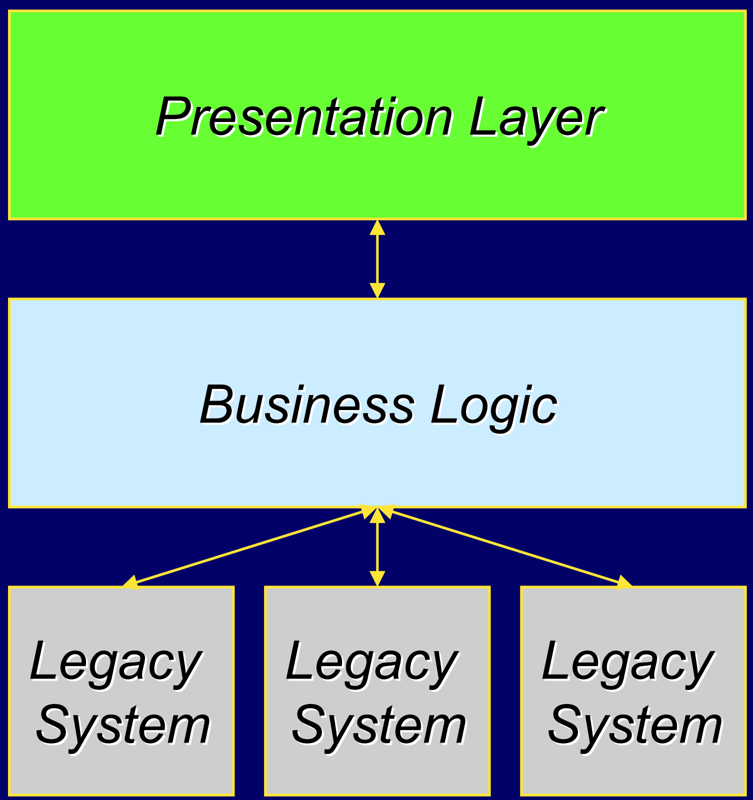
What's required?

What is status?

Dynamic Process Visualization – TTWCS

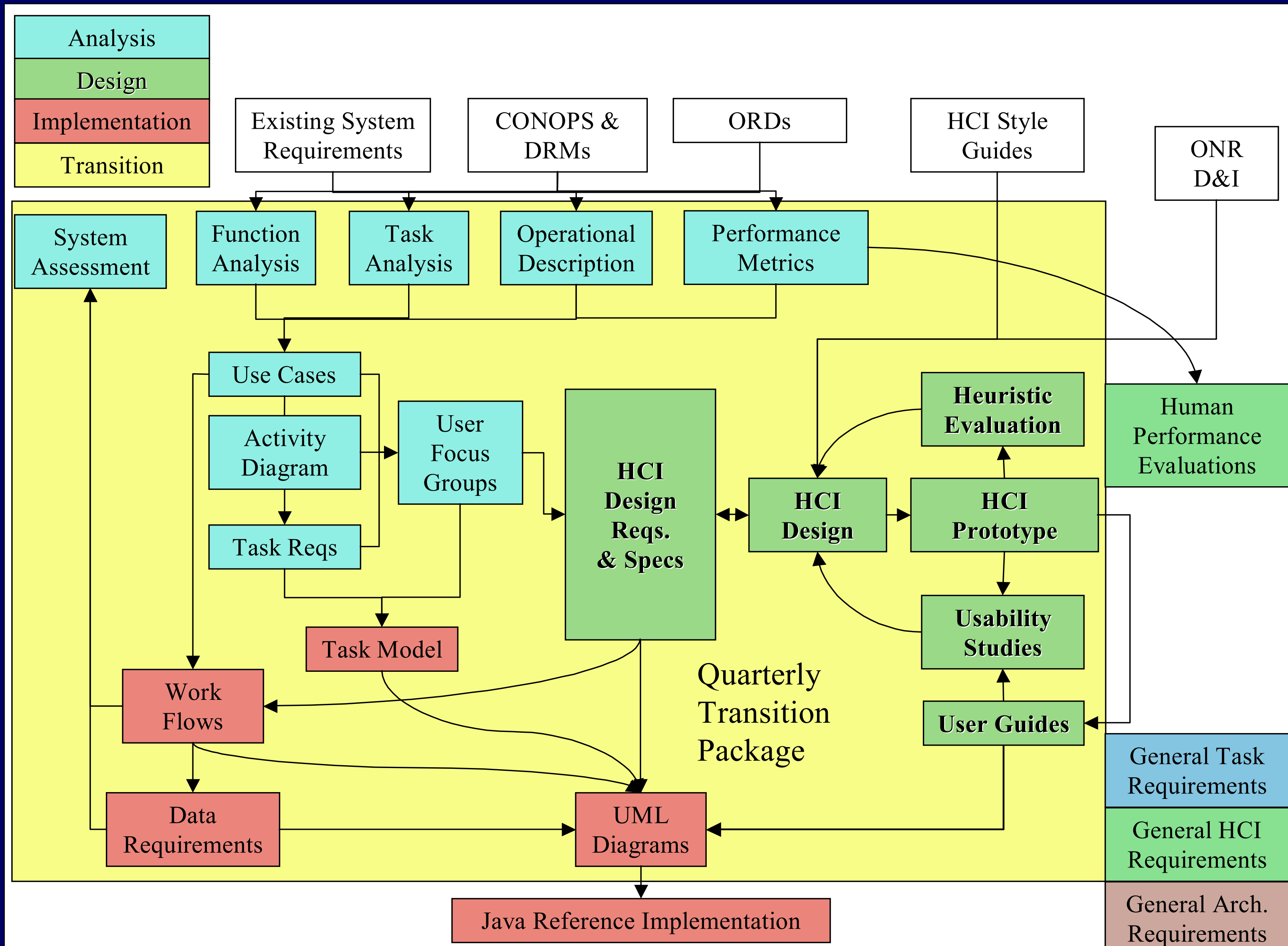


Separate Presentation Layer

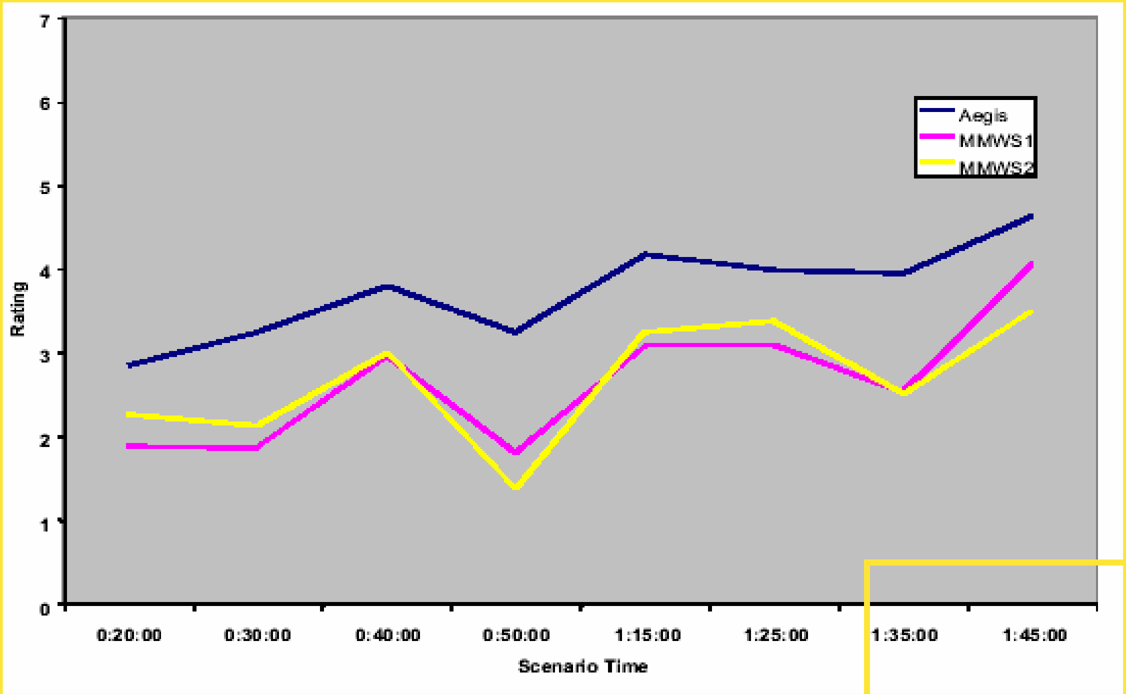


- Mods can be made to the presentation layer without effecting legacy code.
- Decision aids can be shared across legacy systems.
- Mods can be made once and apply to all legacy systems.

UCD Transition Process



Performance Metrics



	Kinematics	Query/ Warning	Engage ASM
Aegis Teams	1 of 8	2 of 8	7 of 8
MMWS V1	6 of 6	6 of 6	6 of 6
MMWS V2	2 of 2	2 of 2	2 of 2

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Fleet Usability Testing Within Spiral Development

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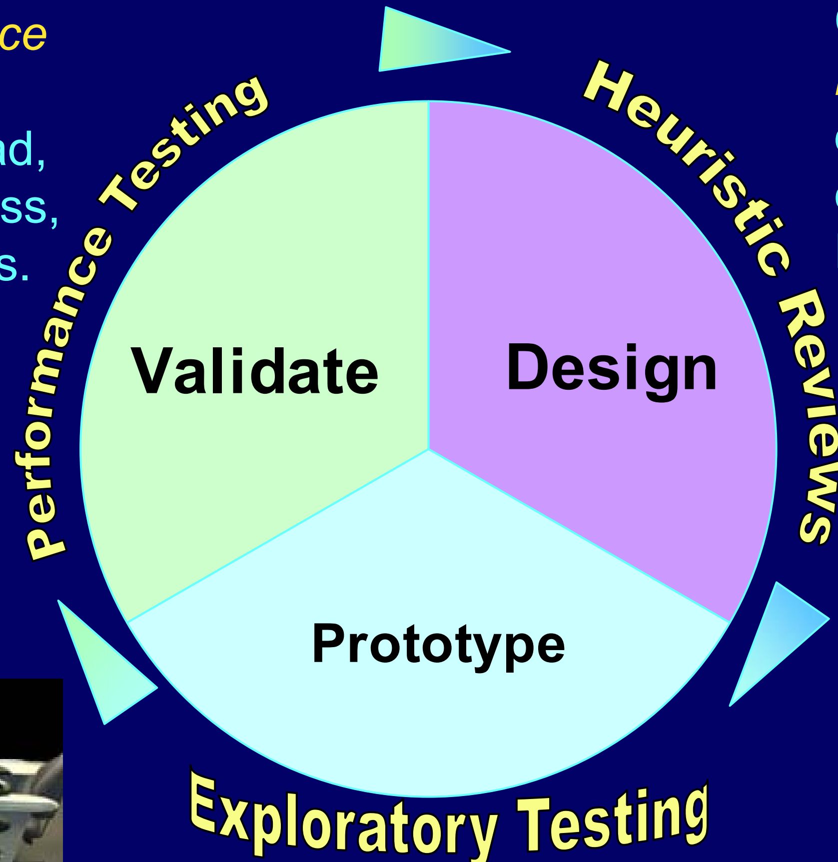
Conduct *performance testing* to measure throughput, workload, situational awareness, and team processes.



Conduct *heuristic reviews* to ensure designs follow established Human Factors principles.

Conduct *exploratory testing* to iterate on initial designs and evaluate alternative design concepts.

Research Summary

- Effective design of supervisory control systems is a key force towards transformation.
- Performance, efficiency, crew size optimization and ultimately training and operational costs are affected.
- Key enablers are:
  - HCI design
  - Information architecture
  - Design process

Transformational Tradeoffs: New Technologies or More People

- Metrics for HFE design success are compelling
- Systems designed with reduction in crew size induced *better* performance
- Metrics for manpower costs are not as well developed or robust
- This makes technology and manpower tradeoffs more difficult to quantify

HFE Design Success Produces Improved Results

- Metrics for HFE design success are well established and robust
- For example, with MMWS and a 50% reduction in crew size:
  - Better performance in air defense tasks
  - Less workload induced on operating team
  - Increased situational awareness
- This technology can be extrapolated to other systems and platforms
- HFE design criteria offer the potential for manpower savings in many venues

Manpower Cost Analysis Remains an "Imperfect Science"

- Metrics to quantify the costs of personnel are adequate – to a point
- CNA Study: "Insufficient organizational imperatives exist to mate technology insertion with manpower decisions"
- Manpower models quantify that which can be readily quantified
- "Other" costs are not adequately captured

Manpower Cost Analysis Remains an "Imperfect Science"

- Costs that are effectively modeled:
  - Pay
  - Benefits
  - Pro-rata retirement benefits
  - Health Service Costs
- Costs that are less well accounted for:
  - Recruiting costs
  - Training costs
  - "War zone" costs
  - "War zone" tax benefits
  - Family support services
  - Veterans affairs benefits

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Manpower Cost Analysis Remains an "Imperfect Science"

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- Manpower costs are "blended" across pay grades to reflect a single cost:
  - FY03 USN Officer (O-1 to O-10): $100,106
  - FY03 USN Enlisted (E-1 to E-9): $49,619
- May tend to make legacy systems appear to be more cost-effective than newer HFE designed technologies by obscuring the fact that more junior, less-experienced personnel can be trained on new systems that supplant legacy systems

C4ISR Transformation Challenge: Integrating the HFE Discipline

- Military transformation has traction
- Demand for manpower-efficiency growing
- HFE C4ISR designs offer great promise
- Tradeoffs must be objective
- Ability to measure systems design robust
- Manpower models must catch up

Military Transformation End Game: Enhanced Manpower Effectiveness

- Transformation is about more than just technology
- Technology insertion and manpower savings not a one-to-one relationship
- HFE Discipline can guide most effective manpower savings methodologies
- Ultimately, cost-benefit analysis must be applied to prioritize technology insertion

Importance of Realizing Manpower Savings Demands Enhanced Models

- Technology insertion likely to be increasingly tied to manpower savings
- Life-cycle costs of military operators must be better quantified
- Underestimating manpower costs = less transformational technology insertion
- This could ultimately retard transforming military forces

Summary

- Potential to "design the system around the human" remains high
- Potential for concomitant manpower reductions remains high
- Refining manpower models one key to developing precise metrics
- Unless or until these models are refined, technology insertion will likely suffer

Questions